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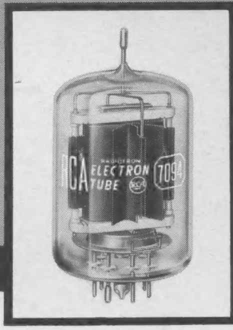

DETERMINATION OF TYPICAL OPERATING CONDITIONS

For RCA Tubes Used as Linear RF Power Amplifiers

Part II

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As noted in the last issue (December, 1960), ham interest in single-sideband transmission has been on a continual upswing during the past few years. This interest has prompted publication of numerous articles on the theory and construction of linear triode and tetrode amplifiers. While these articles have discussed classes of tube operation and compared grid-drive to cathode-drive circuits, only a handful provided design information for adapting tube manufacturers' data to available components or to the amateur's specific requirements.

Included among the "selected few" was an article by A. P. Sweet, which appeared in the December, 1954, issue of HAM TIPS. It presented such information in the form of step-by-step calculations for use in converting published maximum ratings to typical operating conditions.

Having recognized the need to bring this design information up to date, HAM TIPS—in the last issue—featured Part I of a two-part article prepared by W3FAL. This first part extended the calculations to include cathode-drive (grounded-grid) operation of tetrodes and triodes in class AB_1 service.

Now, in this issue, Part II covers the procedure for calculating typical operating conditions for class B operation of triodes or triode-connected tetrodes in a cathode-drive circuit.

Sample calculations are based on published data and curves for the RCA-7094 power tetrode. (The last issue also included a chart listing maximum ratings and typical operating conditions for several widely used RCA power tubes.)

Class B Operation of Triodes Or Triode-Connected Tetrodes (Cathode-Drive Circuit)

Hams who want to operate tubes at conditions other than those given in the published data can calculate typical operating conditions from the maximum ratings and characteristics curves. Follow the procedure enumerated below to figure the typical operating conditions for class B operation of triodes or triode-connected tetrodes in a cathode-drive circuit. This procedure may be adapted to grid-drive service by elimination of step 13 and of the term P_{ft} from steps 14 and 15. (P_{ft} is one of 21 symbols which are defined on page 2.)

(1) Make sure that E_b is within maximum ratings.

(2) Assume a value of I_{bms} approximately

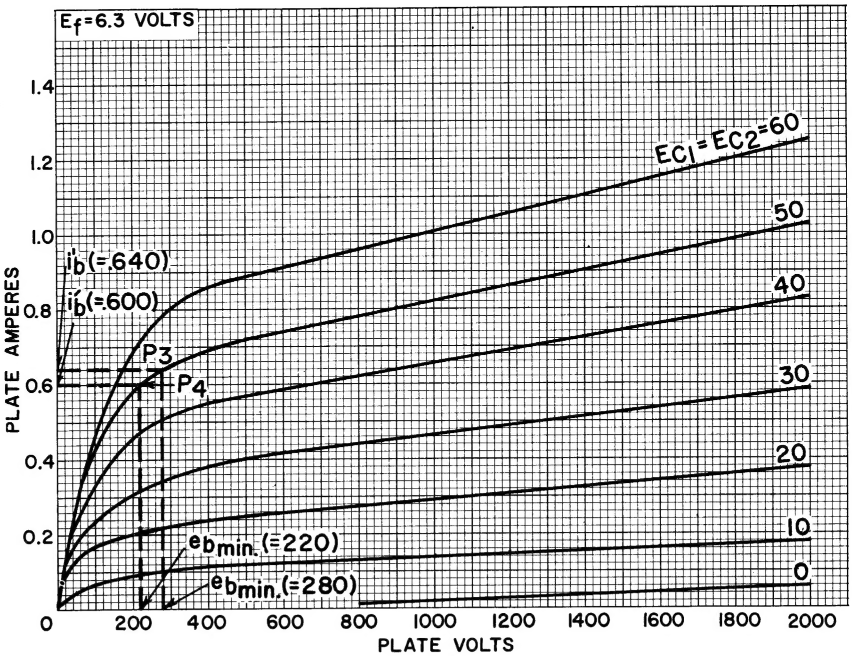

Figure 1: Typical plate characteristics of type 7094 triode connection (grid No. 1 connected to grid No. 2).

E_b	*DC plate voltage (with respect to cathode)*
e_{bmin}	*Minimum plate voltage necessary to produce the required peak current (from the characteristics curves)*
E_{c2}	*DC screen-grid voltage*
E_{c1}	*DC control-grid voltage*
e_{cm}	*Maximum control-grid drive voltage needed to obtain the required peak plate current at a given minimum plate voltage*
E'_g	*Peak value of control-grid voltage swing*
I_{bms}	*Maximum signal, dc plate current*
I_{bo}	*Zero-signal, dc plate current*
i'_b	*Instantaneous peak plate current*
I_{c1}	*Maximum-signal, dc control-grid current*
I_{c2}	*Maximum-signal, dc screen-grid current*
i'_{c1}	*Instantaneous peak control-grid current*
i'_{c2}	*Instantaneous peak screen-grid current*
PD	*Plate dissipation at maximum signal*
PD_o	*Plate dissipation at zero signal*
PI	*Plate power input at maximum signal*
PO	*Power output at maximum signal*
P_{ft}	*Feed-through power at maximum signal (cathode-drive operation)*
DP	*Driving power at maximum signal*
SI	*Screen-grid input at maximum signal*
R_p	*Effective rf plate-load resistance*

equal to 3 (rated maximum PD)/E_b. This value should be within the maximum ratings for the tube. If it is not, use the maximum rated value of I_{bms}.

(3) Calculate I_{bo}: $I_{bo} = I_{bms}/5$.

(4) Calculate PD_o: $PD_o = E_b I_{bo}$. The value of PD_o should not exceed the CCS plate-dissipation rating. If it does, determine I_{bo} as follows: I_{bo} = rated CCS PD/E_b, and use this value instead of the value obtained in step 3.

(5) Determine E_{c1} from the plate-characteristics curves as the control-grid voltage at which the plate voltage is E_b and the plate current is I_{bo}. For zero-bias operation, I_{bo} is the plate current at the point on the curve for zero control-grid voltage at which the plate voltage equals E_b; calculate $PD_o = I_{bo} E_b$. If the value of PD_o exceeds the CCS plate-dissipation rating, a new point must be selected at a lower value of E_b. If the plate-dissipation rating can be met without drastic reduction of E_b, repeat steps 1 and 2 and continue with step 6.

(6) Calculate i'_b: $i'_b = 3\ I_{bms}$.

(7) From the plate-characteristics curves, select a value of e_{bmin} near the knee of the curves at which i'_b can be obtained; record e_{cm} and $i'_{c1} + i'_{c2}$ for this point.

(8) Calculate PD: PD = $(I_{bms}/4)\ (E_b + 3\ e_{bmin})$.

(9) Calculate $I_{c1} + I_{c2}$: $I_{c1} + I_{c2} = (i'_{c1} + i'_{c2})/4$.

(10) Calculate PI: PI $- E_b I_{bms}$.

(11) Check the values obtained in steps 8 through 10 to determine whether they are within the maximum ratings for the tube type. If the calculated values exceed the maximum ratings, choose a lower value of I_{bms} and repeat steps 3 through 10.

If all the values are well below maximum

ratings, a higher value of I_{bms} can be chosen in step 2, and steps 3 through 10 repeated to see whether the operation is still within ratings. If so, the latter set of operating conditions can be used to provide slightly more power output.

When values slightly below the maximum ratings are obtained for plate dissipation, control-grid and screen-grid currents, and plate input, the corresponding value of I_{bms} represents the maximum value which can be used at the original plate voltage selected. Lower values of I_{bms}, which provide more conservative operation but less power output, can also be used.

(12) Calculate $E'g$: $E'g = |Ec_1| + e_{cm}$.

(13) Calculate P_{ft}: $P_{ft} = E'_g\, i'_b/4$.

(14) Calculate PO: $PO = (E_b - e_{bmin})\, i'_b/4 + P_{ft}$.

(15) Calculate DP: $DP = E'_g\,(i'_{c1} + i'_{c2})/4 + P_{ft}$. In cathode-drive operation, the driver output need be only slightly greater than the calculated DP because P_{ft} is normally large compared to the rf tube and circuit losses.

(16) Calculate R_p: $R_p = E_b/1.7\, I_{bms}$.

* * *

Example—Here is an example that illustrates the calculation of typical operating conditions for class B triode-connected ICAS operation of the 7094 tetrode in a cathode-drive circuit:

(1) The maximum plate-voltage rating is 2000 volts.

(2) $I_{bms} = 3$ (rated ICAS PD)/E_b = 3(125)/2000 = 0.188 ampere; this value is within ratings.

(3) $I_{bo} = I_{bms}/5 = 0.188/5 = 0.038$ ampere.

(4) $PD_o = E_b\, I_{bo}$ = (2000) (0.038) = 76 watts; this value is within the CCS plate-dissipation rating.

(5) E_{c1} can be determined from the plate-characteristics curves shown in Figure 1 as the grid voltage at which the plate voltage is 2000 volts and the plate current is 0.038 ampere; $E_{c1} = -2$ volts. Because this value is quite close to zero, zero-bias operation may be possible at the same or a slightly lower E_b. When E_b equals 2000 volts on the curve for zero control-grid voltage, I_{bo} is 0.060 ampere.

Recalculate step 4 using this value: PD_o = (2000) (0.060) = 120 watts.

Because this value exceeds the maximum CCS plate-dissipation rating, a lower value of E_b must be chosen. At the point where E_b is 1750 volts, I_{bo} is 0.050 ampere.

Recalculate step 4: PD_o = (1750) (0.050) = 88 watts.

This value is within ratings. Recalculate step 2 and continue with step 6.

$I_{bms} = 3(125)/1750 = 0.214$ ampere.

(6) $i'_b = 3\, I_{bms} = 3(0.214) = 0.642$ ampere.

(7) Select a point P3 on knee of one of the curves shown in Figure 1 at which i'_b equals 0.642 ampere. At this point, e_{cm} is + 50 volts and e_{bmin} is 280 volts. From the curves shown in Figure 2, $i'_{c1} + i'_{c2}$ equals 0.520 ampere.

(8) $PD = I_{bms}/4\,(E_b = 3\, e_{bmin}) = 0.214/4\,[1750 + 3\,(280)] = 139$ watts.

(9) $I_{c1} + I_{c2} = (i'_{c1} + i'_{c2})/4 = 0.520/4 = 0.130$ ampere.

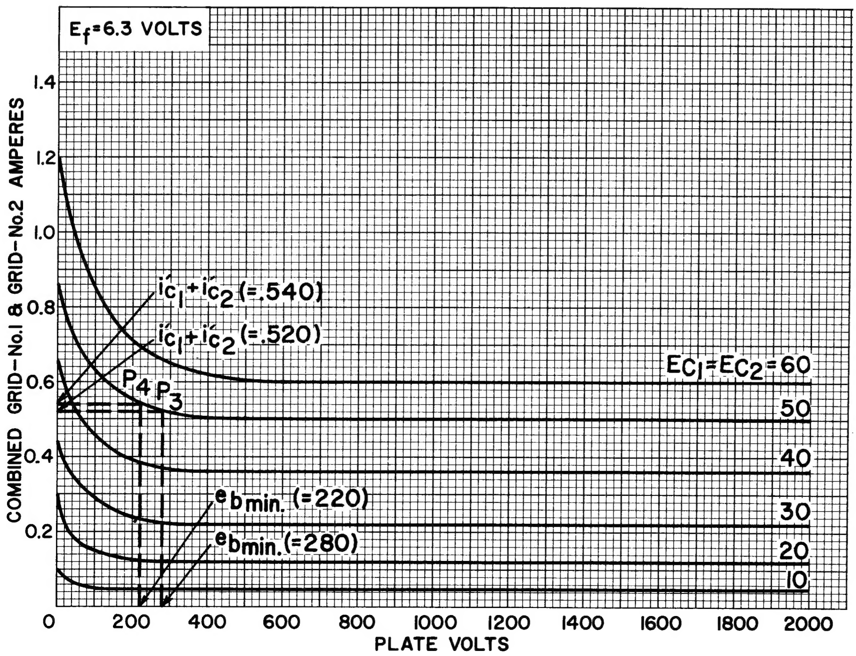

Figure 2: Typical grid characteristics for type 7094 triode connection (grid No. 1 connected to grid No. 2.)

(10) $PI = E_b I_{bms} = (1750)(0.214) = 375$ watts.

(11) Because the value of PD obtained in step 8 is above the maximum ICAS rating, select a lower value of I_{bms} to obtain a lower value of i'_b and e_{bmin}, and recalculate steps 6 through 10.

$I_{bms} = 0.200$ ampere.

$i'_b = 3\ (0.200) = 0.600$ ampere.

At the new point P4, $e_{cm} = +50$ volts, $e_{bmin} = 220$ volts, and $i'_{c1} + i'_{c2} = 0.540$ ampere.

$PD = 0.200/4\ [1750 + 3\ (220)\ ] = 120$ watts.

$I_{c1} + I_{c2} = 0.540/4 = 0.135$ ampere.

$PI = (1750)\ (0.200) = 350$ watts.

All values are now within ratings; therefore, the remainder of the calculations can be completed.

(12) $E'_g = |E_{c1}| + e_{cm} = 0 + 50 = 50$ volts.

(13) $P_{ft} = E'_g\, i'_b/4 = 50\ (0.600)/4 = 7.5$ watts.

(14) $PO = (E_b = e_{bmin})\ i'_b/4 + P_{ft} = (1750 - 220)\ (0.600)/4 + 7.5 = 237$ watts.

(15) $DP = E'_g\ (i'_{c1} + i'_{c2})/4 + P_{ft} = (50)\ (0.540)/4 + 7.5 = 14$ watts.

(16) $R_p = E_b/1.7\ I_{bms} = 1750/(1.7 \times 0.200) = 5100$ ohms.

These values compare reasonably well with the published values.

* * *

Conclusion—Table I (published in the last issue: December, 1960) shows the maximum ratings and typical operating conditions for several popular RCA tubes in linear rf amplifier service for single-sideband, suppressed-carrier service.

It should be remembered that the typical operating conditions shown by the manufacturer (or calculated by the preceding methods) are only approximate. Minor adjustments are usually made in actual operation by slight variation of the control-grid bias or screen-grid voltage. In linear rf amplifier circuits for single-sideband, suppressed-carrier transmission, it is particularly important to check the actual operating conditions when the transmitter is first set up to assure that linear operation within the maximum tube ratings is being obtained.

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Harvey Slovik, Editor

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